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DIVISION OF ATTENTION AS A FUNCTION OF THE NUMBER OF STEPS, VISUAL SHIFTS, AND MEMORY LOAD*

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Abstract

An experiment has been done to study the effects on divided attention of visual shifts and long-term memory retrieval during a monitoring task. A concurrent vigilance task was standardized under all experimental conditions. The results show that subjects can perform nearly perfectly on all of the time-shared tasks if long-term memory retrieval is not required for monitoring. With the requirement of memory retrieval, however, there was a large decrease in accuracy for all of the time-shared activities. It was concluded that the attentional demand of long-term memory retrieval is appreciable (even for a well-learned motor sequence), and thus memory retrieval results in a sizable reduction in the capability of subjects to divide their attention. Also, a selected bibliography on the divided attention literature is provided.

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INTRODUCTION

This research is an outgrowth of our interest in problems of divided attention that are associated with avionic computer systems. Unlike many other man-computer interactions, the pilot has other time-shared duties besides interacting with the onboard computer. Furthermore, existing avionic computer systems have employed a variety of designs for the man-computer interaction, but virtually nothing is known about the attentional demands of these designs. Some systems are perhaps easier than others to operate in the context of time-shared attention. However, few generalities can be learned from the direct study of existing avionic designs since these designs simultaneously vary on too many dimensions which many affect divided-attention performance. Also, field tests are too unstructured and uncontrolled to learn about the mechanisms affecting performance on time-shared tasks. Thus, in the present research, a controlled laboratory study on divided attention is employed in order to identify the critical dimensions that affect the sharing of attention. Ultimately, the goal of the laboratory studies is the establishment of design guidelines for future man-computer systems. More specifically in this study the number of steps, shifts in visual angle, and information retrieval from long-term memory were investigated.

METHOD

Subjects

Twelve male undergraduates at Tufts University served as subjects. Each subject received $20.00 for their participation in three sessions for a total of three-and-a-half hours.

Design

There were three experimental tasks performed in a time-sharing manner. The experimental tasks consisted of:

1. A monitoring task with three response buttons.
2. A vigilance task with a single response button.
3. A recall task of a four-digit number.

Moreover three independent variables were manipulated corresponding to the parameters of the monitoring and recall tasks. The independent variables consisted of:

1. The physical distance separating the three monitor-response buttons.
2. The sequence required for pressing the monitor-response buttons.
3. The amount of delay between the presentation of the memory item (i.e. the four-digit number) and the recall test. (This delay was scaled in terms of a regularly spaced monitoring stimulus, and henceforth the delay will be referred to as the memory lag. Thus, a memory lag of n has n monitoring stimuli occurring between the memory item presentation and the recall test.)

The parameters of the monitoring task were varied among three experimental sessions. The values for recall lag cut across the experimental sessions and all values were tested at each session.

In session A, the physical arrangement of the monitor buttons was a horizontal line across the top of the console. The buttons were 3 cm apart, center to center, creating a visual angle of approximately 3^{o} for the subject. The sequence required for monitor button presses was free, except that all buttons were to be used equally and no button could be pressed twice consecutively.

Session B differed from A principally in the arrangement of the monitor-response buttons. The configuration of their placement formed a 30 cm equalateral triangle with a button at each corner. The visual angle was approximately 28^{o} between any two buttons.

Session C was also similar to Session A except that a set sequence was required for the monitor button presses. The configuration of the monitor buttons was at the top of the console, as in session A, but the subject was required to press the monitor buttons according to a previously learned pattern.

Apparatus and Procedure

The subject was seated approximately 60 cm in front of a console with 4 buttons and a 9 cm voltmeter face. Three of the buttons were designated as monitor-task buttons and the fourth was designated as the vigilance-task button. All stimulus presentations were under the control of a Sony TC630 stereo tape recorder. The subject's button presses were recorded by event markers on a Narco-Bio Physiograph Six polygraph. All stimulus events were recorded on a separate channel of the polygraph. Recall task stimuli were presented by a Kodak Carousel Projector that was switched by a Lafayette Voice Key. The vigilance task stimulus was switched on by a Uher F422 diapilot. See Figure 1 for a more detailed apparatus schematic.

Each trial began with the 0.5 sec. visual presentation of a random four-digit number. Number stimuli were screened for highly meaningful patterns and those beginning with zero were also excluded. The monitoring task and the vigilance task followed immediately in a time sharing manner. Each trial contained 18 monitor stimuli, presented at a rate of one per 1.25 sec. The monitor stimulus consisted of an audible 0.25 sec. 600 Hz tone which produced an 8 volt deflection at the console meter. The vigilance stimulus was a needle deflection of an additional 6 volts occurring simultaneously with the monitor tone. Six vigilance stimuli were distributed randomly within each trial. The monitor task and the vigilance task were interrupted after lags of 0, 2, 4, 6, or 8 tones for a 3.75 sec. recall test of the memory item for that trial. At the conclusion of the recall interval, monitoring and vigilance resumed for the remaining portion of the trial. The subject was allowed a 5 sec. rest after every trial.

Each experimental session consisted of 90 trials. Eighteen replications of each interrupt lag condition were distributed randomly throughout each session. Each subject participated in all three experimental sessions. The order of participation in session A, B, and C was counterbalanced across the twelve subjects. Prior to the first session, each subject received training on each of the separate experimental tasks and four practice trials in which they were performed in a time-sharing man-

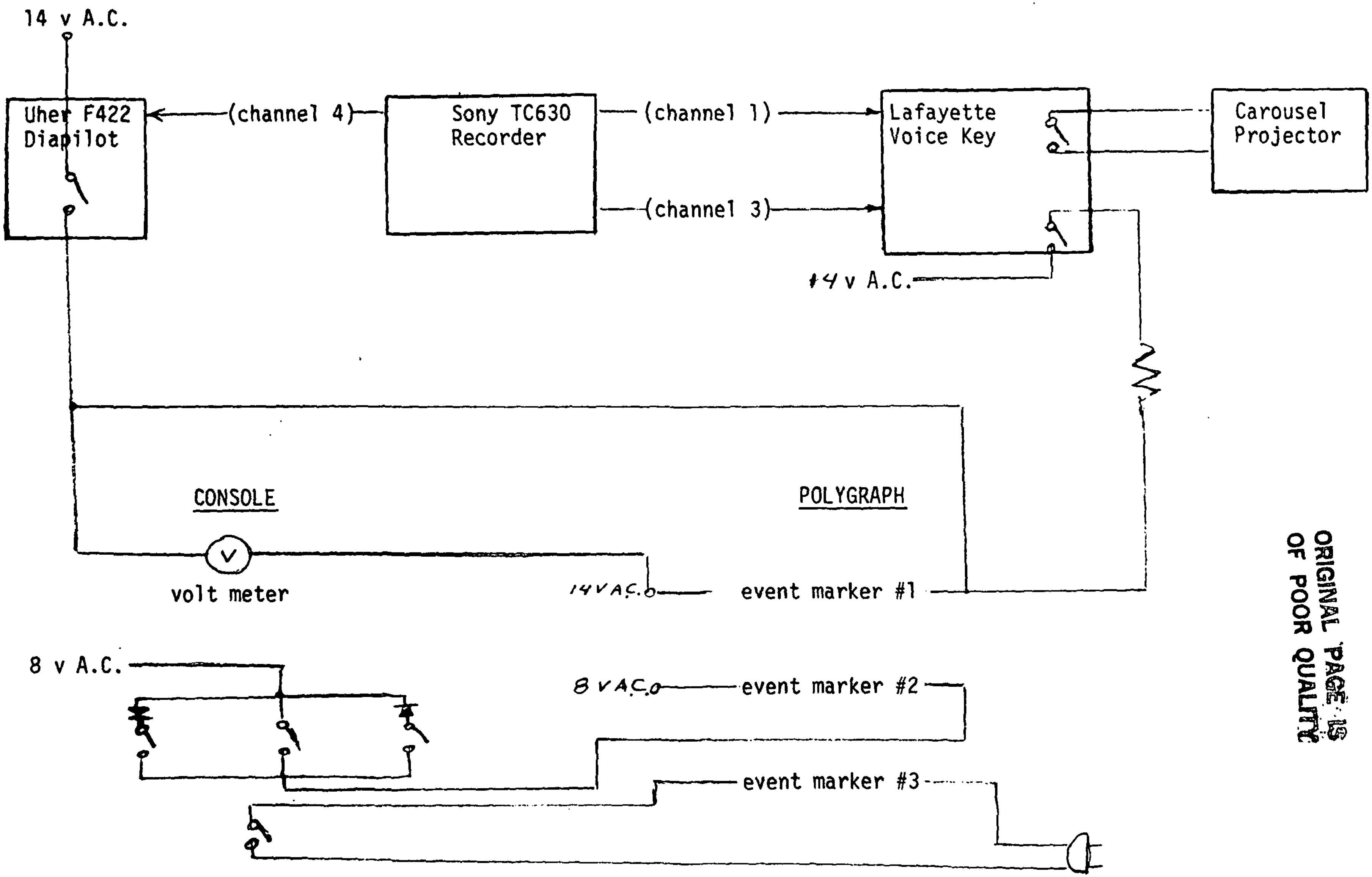

Figure 1 Apparatus schematic

ner. Prior to Session C, the subjects were given one day to memorize the set sequence of 18 monitor-button presses. Also, before Session C began, the subjects had to demonstrate that they, in fact, learned the sequence for monitoring.

RESULTS AND DISCUSSION

The results are broken into three sections corresponding to the three time-shared tasks. Moreover, prior to performing statistical tests, percentage data were transformed by a standard arcsine transformation in order to better assure the conditions of normality.

Monitor Task

The overall results for this task are quite clear as shown in Table 1. Performance is extremely accurate in both Sessions A and B, but decreases considerably in Session C. Since performance was so accurate in Sessions A and B, the data for these experiments were pooled and compared to the Session C data. The mean monitor accuracy is significantly less in Session C, $t(11) = 4.73$, $p < .001$.

TABLE 1

MEAN PROBABILITIES OF CORRECT RESPONSES, INCORRECT RESPONSES, MISSES AND FALSE ALARMS FOR EACH SESSION IN THE MONITOR TASK

	Session		
Response Type	A	B	C
Correct	.996	.994	.794
Incorrect	.002	.001	.175
Miss	.001	.003	.026
False Alarm	.001	.002	.005

In order to explore the nature of the reduction in accuracy in Session C, a number of subsequent analyses were performed. Figure 2 shows the probability of a correct sequence of button presses as a function of sequence length. Note that this curve is necessarily a decreasing function since an error at any monitor step number means that the sequence is also incorrect. Nevertheless, the performance in Sessions A and B is highly accurate for all sequence lengths, but accuracy is lower in Session C for all sequence lengths. The probability of a correct monitor sequence of 18 button presses is greater in Session A and B than the probability of even a one member sequence in Session C. Thus the requirement of recalling the monitoring sequence from long-term memory has a sizable effect on monitoring accuracy.

The actual recall of the four-digit memory item is an interruption from the monitoring and vigilance tasks. Figure 3 shows monitor accuracy relative to the interrupt occurrence. Performance is uniformily high in

Sessions A and B, although there is a slight decrease occurring just prior and subsequent to the interrupt. The data from Session C show that performance is higher before the interrupt than after the interrupt.

In the previous analysis the 0-lag data were omitted since the monitoring and vigilance tasks are not interrupted in the 0-lag condition. Figure 4 displays the monitoring accuracy as a function of monitor step number for the 0-lag condition. This display thus eliminates the effects of interrupts on monitoring. The curve for Sessions A and B is quite flat, again reflecting the high performance level in those conditions; however, the curve for Session C is uniformly lower.

Overall then, there was no effect found on monitoring performance for the spatial arrangement of the monitor buttons. Thus, large visual angle shifts of 28^{o}, that are required in Session B, did not significantly affect the monitoring accuracy. However, requiring the retention of a set monitoring sequence in Session C did produce a dramatic decrease in performance.

Vigilance Task

The overall results for the vigilance task are shown in Table 2. Again, performance is very accurate in Sessions A and B and decreases in Session C. Since performance was equivalent in Sessions A and B, the results of these sessions were again pooled and compared to the data from Session C. The comparison of overall accuracy showed that performance

TABLE 2

MEAN PROBABILITIES OF CORRECT RESPONSES, MISSES AND FALSE ALARMS FOR EACH SESSION IN THE VIGILANCE TASK

	Session		
Response Type	A	B	C
Correct	.997	.995	.974
Miss	.007	.011	.068
False Alarm	.001	.003	.006

decreased significantly in Session C, $t(11) = 7.018$, $p < .00005$. As is evident in Table 2, this performance decrease is almost entirely due to an increase in miss rates since false alarm rates are very low in all three sessions. Further analysis shows that not only the overall rate, but also the pattern of errors changed in Session C. In Sessions A and B 63% of the errors occurred over the first nine monitor step numbers, while only 46% occurred for these monitor numbers in Session C. The memory load in Session A and B is largely provided by only the retention of the four-digit number which is required only for first part of the monitoring sequence. However, for Session C there is a memory load throughout the entire sequence since the monitor sequence itself must be recalled from memory. This difference is consistent with the observed patterns of vigilance errors.

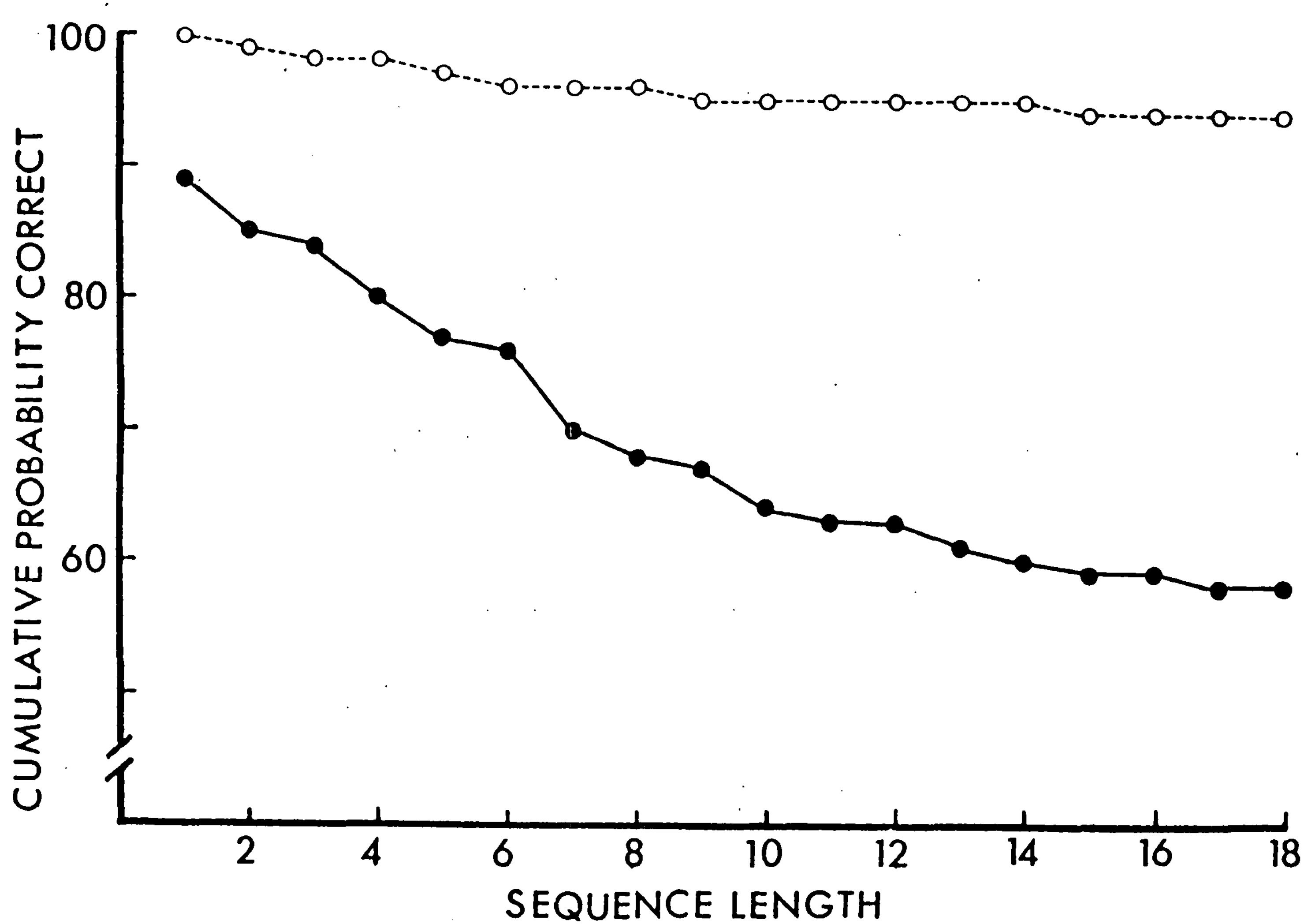

Figure 2. Mean cumulative probability of a sequence of correct monitor responses as a function of sequence length. The open circles represent data averaged over sessions A and B. The closed circles represent data from session C.

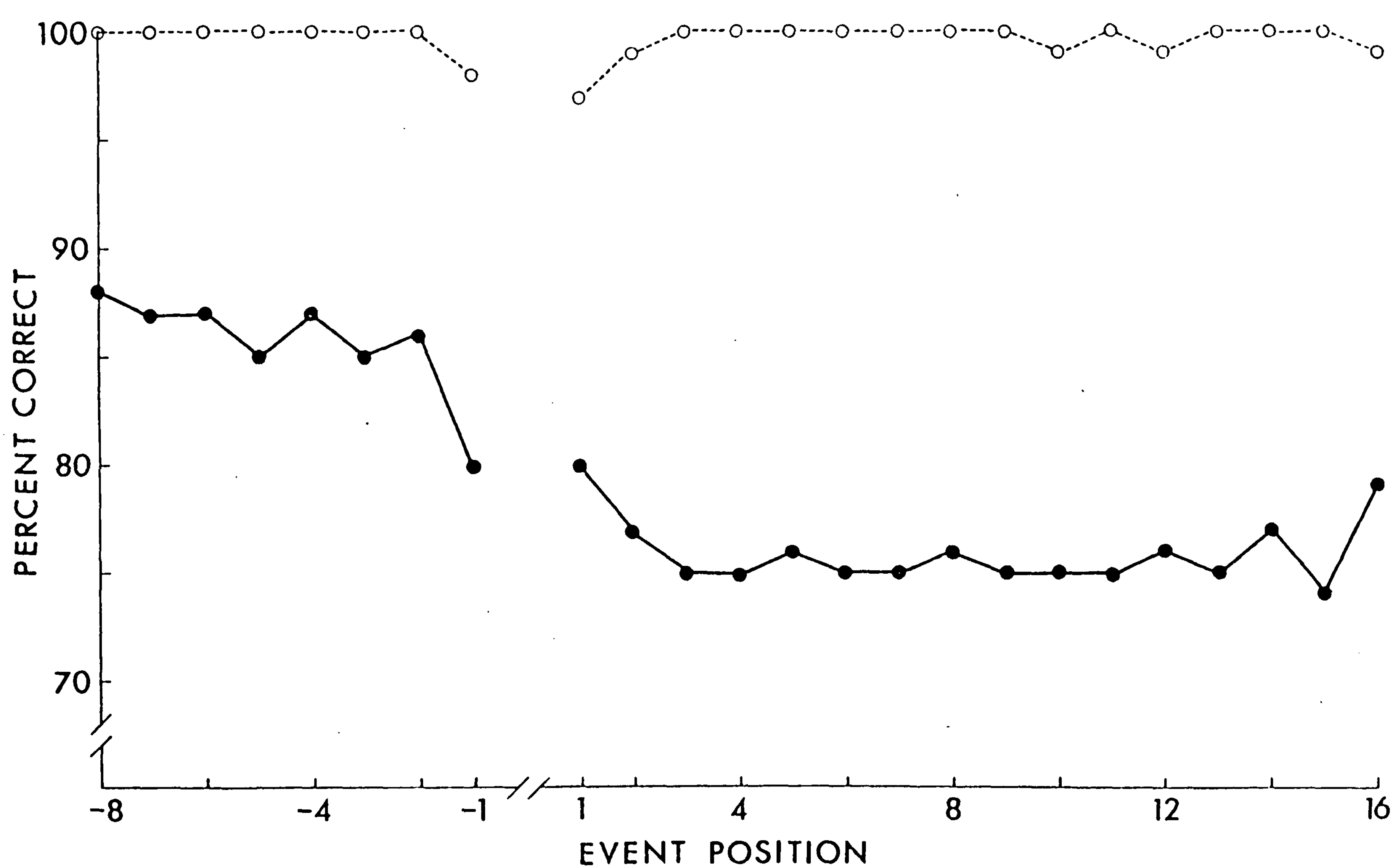

Figure 3. Mean percentage of correct monitor responses as a function of event position. Event position is determined relative to the recall interrupt. The open circles represent data averaged over sessions A and B. The closed circles represent data from session C. Only data from trials with a lag of 2,4,6, or 8 are shown here.

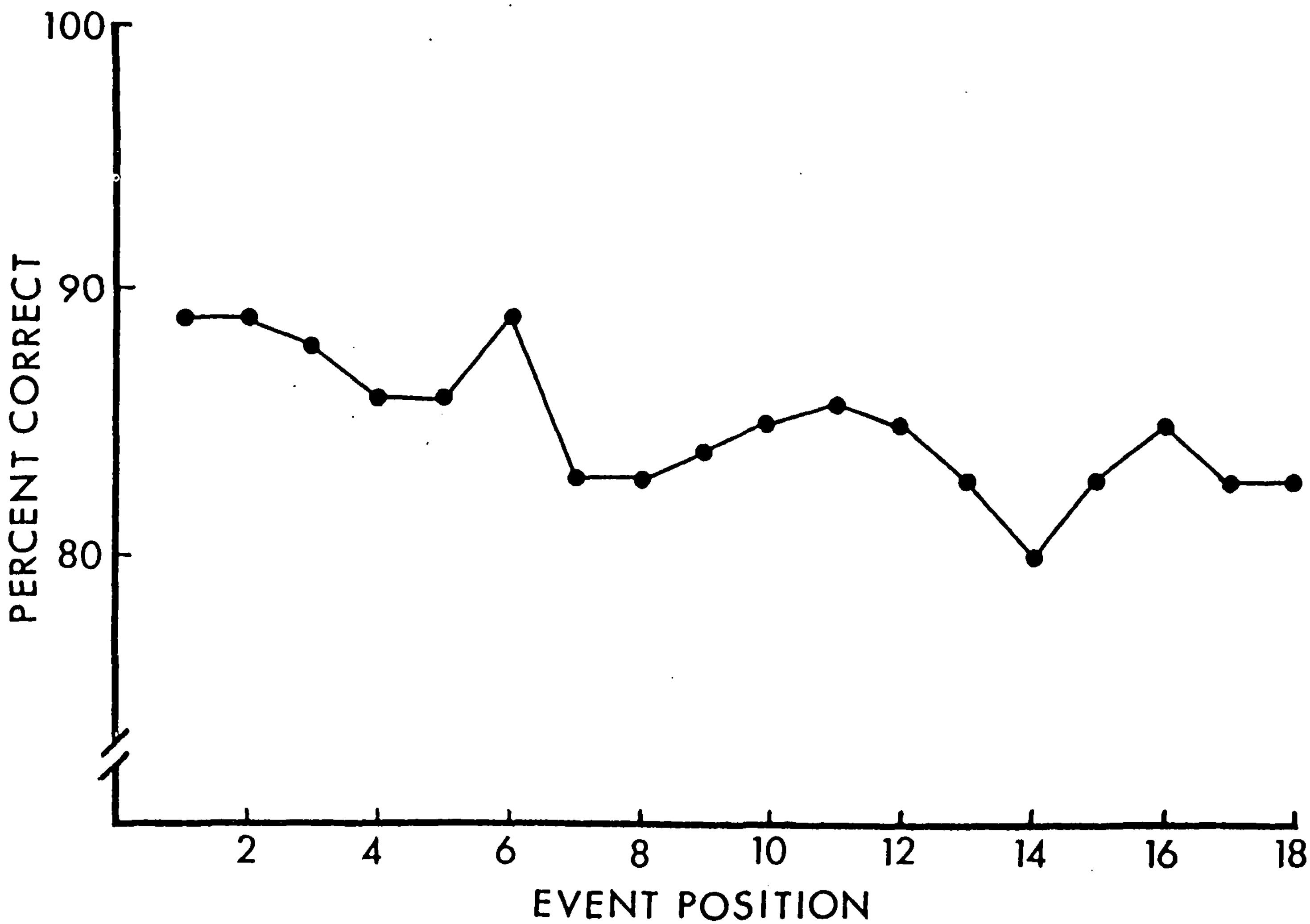

Figure 4. Mean percentage of correct monitor responses on trials with a lag of 0 in session C as a function of event position.

In general the results of the vigilance task are consistent with the monitor results. There is no effect of spatial array found, however, a highly significant decrement in performance occurs in Session C when long-term memory of the monitoring sequence is required.

Results from the Memory Task

The mean percent of recall is shown in Table 3 as a function of session and lag. Analysis of variance was conducted on these data, and it showed significant main effects of both session ($F(2,22) = 8.71$ $MSE = .0064$, $p < .005$) and lag ($F(4,44) = 6.87$, $MSE = .0247$, $p < .001$). The session effect resulted from a significant decrease in recall performance in Session C below the very accurate levels maintained in both Sessions A and B. This difference was quite consistent across all lag levels. Although these differences tended to increase as lag increased, there was no significant interaction between session and lag. The main effect of lag is due to the decrease in recall as the number of interpolated events increases. This effect is consistent across all sessions, but somewhat attenuated by ceiling effects in sessions A and B.

TABLE 3

MEAN PROBABILITY OF CORRECT RECALL IN THE MEMORY TASK
AS A FUNCTION OF SESSION AND LAG

	Lag				
Session	0	2	4	6	8
A	.991	.986	.990	.977	.977
B	.995	1.00	.990	.990	.976
C	.981	.972	.954	.940	.893

Overall, the results of the memory task are very similar to those found in the monitor and vigilance tasks. Subjects maintain very accurate performance in Sessions A and B, but recall of a set sequence in the monitor task results in a significant decrease in the recall of the four-digit memory item.

SUMMARY AND CONCLUSIONS

The combined results of the monitor, vigilance and memory tasks form a clear pattern. The data from Session A establish that subjects can successfully divide their attention across these three tasks. The results of Session B indicate that increases in visual angle for the monitoring task does not impair performance in any of these tasks. In contrast, requiring subjects to recall a set sequence in the monitor task produces a significant decrease in accuracy in all three tasks. Thus, the information processing of recalling the next action of a memorized sequence of button

presses impairs processing in other concurrent tasks. The retrieval from long-term memory of the next action requires attention that otherwise could have been directed to the time-shared activities. The attentional demand of memory retrieval is appreciable and hence results in a sizable decrease in divided-attention performance. However, without the involvement of long-term memory retrieval, subjects perform nearly perfectly on the time-shared tasks of recalling a recently presented random number and of performing motor responses to monitor and vigilance stimuli.